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RESEARCH PAPER

Comparison of Carbon Stocks Between Mixed and Pine-Dominated Forest Stands Within the Gwalinidaha Community Forest in Lalitpur District, Nepal

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Abstract Forests play an important role in the global carbon cycle as both a source and sink of carbon. The carbon stock in a forest is affected by climate, tree species and forest management. The community forestry program of Nepal has been successful in reviving degraded forest patches in the Mid-hills but there is a lack of information whether mixed or pine plantations store more carbon. This study estimated and compared carbon stocks in mixed and pine-dominated forest stands within the Gwalinidaha Community Forest of Lalitpur District, Central Nepal. Carbon components considered include tree biomass carbon, root biomass carbon, litter biomass carbon and soil organic carbon. Total carbon stock of the forest is estimated to be 2,250.24 tons with average carbon stock of 166.68 tons/ha. Total carbon stock per hectare was found to be higher in the pine-dominated forest as compared to mixed forest due to the larger tree biomass although the litter carbon and soil organic carbon estimates are higher in the latter. The Community Forestry of Nepal has a huge potential for carbon storage and the pine-dominated forest has a greater carbon stock than mixed forest.

Keywords Biomass · Community Forest · Mid-hills · $REDD^{+}$ · Sequestration

Introduction

Terrestrial ecosystems play an important role in the global carbon cycle (Lal 2005). Carbon is exchanged naturally between these systems and the atmosphere through

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photosynthesis, respiration, decomposition and burning. Forests capture and retain a large amount of carbon over a long period. About 31 % of the earth's land surface is covered by forest which is estimated to hold a total carbon content of 289 Gt in biomass (FAO 2010), more than the amount of carbon in the entire atmosphere. Carbon stocks are dynamic in forests and are largely affected by land-use changes, soil erosion and deforestation (IPCC 2000). Global reduction of forest areas resulted in annual loss of 0.5 Gt of carbon stocks in forest biomass between 2005 and 2010 (FAO 2010). Deforestation contributed about 5.8 $GtCO_2$/year to global greenhouse gas emissions in 1990s (Karousakis 2007). Preventing deforestation is thus a globally recognized mitigation measure to reduce climate change in the short term (IPCC 2007) and is gaining the attention of scientific communities, and carbon negotiation mechanisms including REDD (reduced emission from deforestation and forest degradation) and $REDD^+$ (including forest enhancement and sustainable management) which are now under consideration.

Nepal is one of the pioneer countries in developing and promoting Community Forest (CF) programs (Paudyal et al. 2006; Pandit et al. 2009), in which the forests are handed over to Community Forest Users Groups (CFUGs). This management scheme represents a paradigm shift in the forestry sector of Nepal reflecting devolution of control of forest resources from state to communities (Karky and Skutsch 2010). Over 1.6 M ha of national forest has been handed over to 17,685 (CFUGs) (DOF 2012) throughout the country, most of which is in the Mid-hills. CF is a successful community-based forest management practice in Nepal (Ojha 2008). Even though are some debates about the outcomes of CF in Terai (in the southern plain of Nepal), CF has revived several degraded forests in the Mid-hills (Dahal and Banskota 2009).

The carbon storage potential of forests is being widely investigated and discussed globally after the introduction of the $REDD^+$ mechanism. Because CF is considered a successful forest management program in Nepal, the government and forestry-related non-governmental organizations are interested in including community forestry programs in the $REDD^+$ mechanism. Among other considerations, this requires estimation of the forest carbon stock in community forests. Such estimation is relatively new to Nepal (Shrestha and Singh 2008), and has recently attracted researchers. Estimation of carbon stock creates carbon trading potential of CF and helps CFUGs to realize the importance of CF in regulating global climate which ultimately motivates users towards better forest conservation.

Carbon stock estimation is strongly desirable in both mixed stand and monoculture plantations and warrants promotion by the community forestry program of Nepal. A study from Garhwal Himalaya in India has shown that conifer-dominated forest types have higher carbon storage than broadleaf-dominated forests (Sharma et al. 2010). In this context, this study aims to assess the potential of CF for carbon storage and to compare carbon stocks between mixed forest and pine-dominated stands within Gwalindaha Community Forest in Badikhel Village Development Committee (VDC) of Lalitpur district in Central Nepal.

Ecologically, the study area represents Mid-hills and is located about 15 km south of Kathmandu, the capital city of Nepal. The terrain is hilly and the climate is temperate. The forest with an area of 13.5 ha was handed over to Gwalindaha

CFUG in 1993 under the *Forest Act 1993* for forest protection, management and utilization. The community forest is divided into three blocks by CFUG for management purposes. One block consists of mixed forest and one of pine-dominated forest. In the third block, 50 % is mixed forest and the remainder pine-dominated. *Pinus roxburghii* (Gobre salla) is the dominant species of the pine dominated strata, though there are small areas of other species including *Myrica esculenta* (Kafal) and *Schima wallichi* (Chilaune). *M. esculenta, S. wallichi* and *Alnus nepalnensis* (Uttis) are almost equally distributed in the mixed forest stand.

Research Method

A field study including a forest survey was carried out in March 2011. The sampling intensity of 0.5 % and random samples were used to establish plots in pine-dominated and mixed stands. The whole forest was divided into two strata based on the vegetation (pine-dominated and mixed stands). The stands were of equal areas, 6.75 ha each (GCF 2006). Four plots of 10 m × 10 m were studied randomly in each stratum i.e. mixed forest and pine-dominated forest. In each plot of 100 m^2, the diameters at breast height (DBH) of all the trees inside the plots were measured using a diameter tape, and heights of the trees were measured with the help of clinometers. Standing dead trees, fallen stems and fallen branches with a (DBH) of 5 cm or more were supposed to be measured within the whole sampling size. However, no such dead trees and fallen stems or fallen branches were noticed within the sampling plots. A sampling plot of 1 m × 1 m was prepared in one corner of each 10 m × 10 m plot for litter collection. All the litter within the plot of 1 m × 1 m on the surface was collected and the fresh weight was taken. The litter was then taken to the lab, oven dried at 70 °C for 24 h and dried weight was measured. The soil sample was collected from the centre of the plot of 1 m × 1 m, prepared for the litter collection. A soil sampler, having a length of 18 cm and a diameter of 5.5 cm, was used for the collection of soil samples. The soil samples were taken to the lab of the Central Department of Environmental Science, Tribhuvan University, Kirtipur, Nepal for the determination of soil bulk density and soil organic carbon. The fresh weight as well as the oven-dried weight of soil after 24 h at 100 °C was taken to estimate the bulk density. All the eight soil samples (one sample from each plot) were analysed individually. Soil organic carbon was determined by the Walkley and Black method (Walkley and Black 1934).

Allometric equations developed by Chave et al. (2005) were used for the estimation of tree biomass. The estimation of carbon in a forest ecosystem is mainly premised on the simple fact that about 50 % of total biomass is composed of carbon (MacDicken 1997). Root biomass was estimated on the assumption that the belowground biomass was 25 % of total aboveground tree biomass for temperate broadleaf forest and plantations (IPCC 1996; Mokany et al. 2006). The following formulae were used for computing total above- and below-ground organic carbon.

$$\begin{aligned}&\text{Total aboveground biomass organic carbon}\\&\quad = (\text{total aboveground tree biomass} + \text{total litter biomass}) \times 50\%.\end{aligned}$$

$$\text{Total belowground organic carbon} = \text{total root biomass of tree} \times 50\% + \text{total soil organic carbon.}$$

Estimated carbon was converted to CO_2 equivalent by multiplying total carbon stock by 44/12 (following Shrestha 2009) which is the ratio of the molecular weight of CO_2 to carbon. Total carbon content of the CF was just the sum of total carbon content in two forest types. The data were analysed using SPSS for Windows 11.5.

Results

Total carbon stock of the forest was estimated to be 2,250.24 tons and per hectare stock was 166.68 tons which is the sum of aboveground, root, litter and soil carbon stock. Out of total carbon stock, the pine-dominated forest area had 1,469.67 tons and the mixed forest areas had 780.57 tons of carbon stock. The pine-dominated forest had carbon stock of 217.73 ± 71.05 ton/ha and the mixed forest had 115.29 ± 13.12 ton/ha (Fig. 1a).

The tree biomass carbon stock in the pine-dominated forest area was estimated to be 138.60 ± 54.87 ton/ha which was larger than 43.53 ± 10.03 ton/ha for the mixed forest (Fig. 1b). Root biomass carbon was also higher for pine-dominated

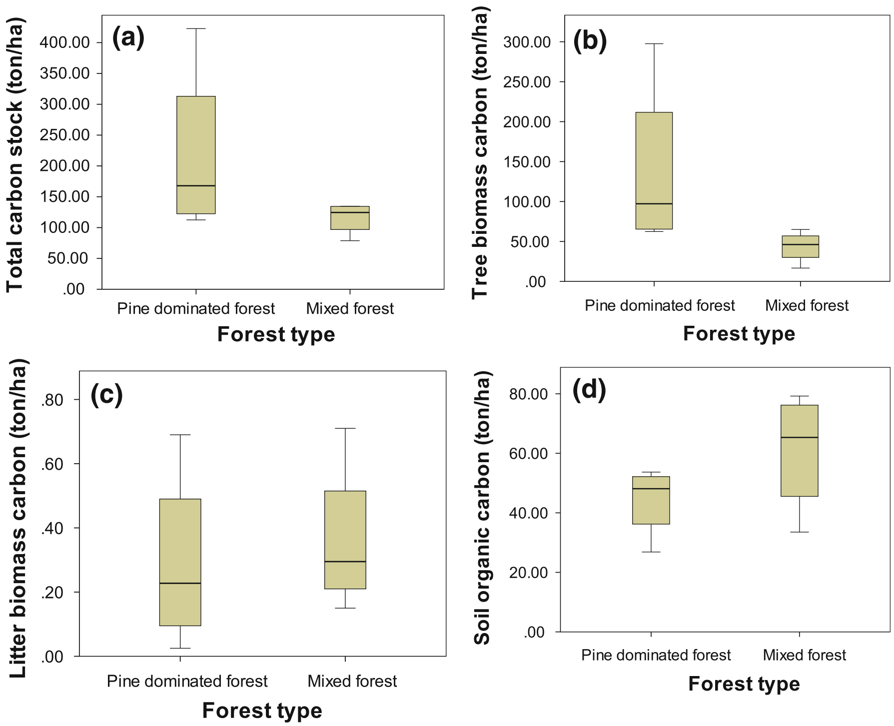

Fig. 1 Box-plot of total carbon stock as **a** aboveground tree biomass carbon, **b** litter carbon, **c** and **d** soil organic carbon in pine-dominated and mixed forest stand

forest (34.65 ± 13.71) than in mixed forest (10.88 ± 2.51). But, litter carbon and soil organic carbon were found to be higher for the mixed forest stand. Litter carbon stock for the pine-dominated forest was found to be 0.29 ± 0.14 ton/ha whereas it was slightly higher for the mixed forest (0.36 ± 0.12 ton/ha) (Fig. 1c). Soil organic carbon was higher in the mixed forest areas than in pine-dominated forest, being 60.86 ± 10.19 and 44.19 ± 6.02 ton/ha for mixed and pine-dominated forest respectively (Fig. 1d).

Based on the total carbon stock (tree, root, litter and soil organic carbon), the community forest with an area of 13.5 ha was estimated to have 8,250.88 ton of atmospheric CO_2 equivalent stored in it.

Discussion and Conclusions

The estimated total carbon stock of Gwalinidaha Community Forest was 150.57 ton/ha. It was higher in pine-dominated forest than in mixed forest stand. The total carbon content per hectare was found to be slightly higher than in a CF of Syanja district in Western Nepal as reported by KC (2012). The mean tree biomass and root biomass carbon of the pine-dominated forest was higher than in mixed forest, whereas mean litter carbon and soil carbon were higher in mixed forest. The most important carbon components of forest carbon is tree biomass carbon that vary among the plots of the same forest as there is considerable variation in tree size and density. Biomass is also affected by the species present and age of trees (Shibuya et al. 2005). Carbon stock per hectare was reported higher in older forest than in a regenerative forest (Ranabhat et al. 2008).

The amount of carbon stock in a forest changes over time due to weather conditions, succession of vegetation and disturbances (Brown et al. 1996; Lal 2005). Moreover, forest management (Jandal et al. 2007), topographic (Prichard et al. 2000) and edaphic factors (Wang et al. 2001) also influence the total carbon stock. Total biomass carbon sequestered was higher in more southerly than northerly facing areas (Karky and Banskota 2006). Furthermore, tree biomass show potential of changes with the forest management activities such as site preparation, soil drainage, selection of species and schedules such as planting and harvesting (Lal 2005). Hence it is important to consider total forest carbon stocks in implementing these activities. This means that the forest need to be regenerated following harvesting and need to be left to grow long enough to reach the previous level of carbon stocks. Removing trees from forests with high carbon stock and planting the area with the species that can grow faster may result only a temporary loss of the forest carbon stock (DAFF 2003; Lemma et al. 2007).

The higher tree biomass carbon content in the pine-dominated stand in this study could most probably be related to faster growth rate of the pine species. Immediately after the handover of degraded forest patches to the user groups, pine plantation were established extensively in Mid-hills of Nepal because this species grows faster than broadleaf species and provides greenery in the bare land changing the landscape appearance quickly. Further, this species is unpalatable and hence least affected by livestock. More than 46 % of the trees were found to have DBH of above 30 cm and

50 % between 10 and 30 cm in the pine-dominated forest, in contrast to 77 % of the trees having DBH between 10 and 30 cm and the remainder <10 cm in mixed forest stand. This indicated that that the mixed forest had many younger plants. A study from Palpa District in Western Mid-hills of Nepal also reported less carbon stock in *Schima-Castanopsis* forest than in pine-mixed forest (Shrestha 2009).

Unlike biomass carbon, soil organic carbon in the forest was found to be higher in the mixed forest than in pine-dominated forest. Low soil organic carbon under pine-dominated forest in relative to deciduous tree plantations was also observed by Paul et al. (2002). Larger soil organic carbon under *Cupressus lusitanica* than under *Pinus patula* and *Eucalyptus grandis* was attributed to higher total litter accumulation and a higher proportion of fine woody litter (branches and coarse roots) in the *Cupressus* stand (Yao et al. 2010). The rate of litter accumulation and its rate of decomposition affect soil carbon. The decomposition of pine litter is very slow (Kainulainen and Holopainen 2002) which might have lessened the soil carbon under pine-forest compared to mixed forest. In a study from Kaski District in Western Nepal (Banskota et al. 2007), there was a difference in soil carbon sequestration between northern and southern aspects of a hill. Total carbon sequestration in the western aspect of a forest in Palpa District was 1.17 times as high as in the northern aspect at an elevation range of 1,100–1,200 m (Shrestha 2009).

Community Forests in Nepal are distributed in diverse ecological zones having different topography, climate and vegetation types. This study represents CFs from Mid-hills where most of the CFs are handed over to CFUGs. CFs in Mid-hills of Nepal have shown great potential for carbon storage and pine-dominated forest stands are more effective for carbon storage than mixed stand. It is not necessary to emphasize mixed plantations over pine plantations in terms of carbon content potential but other ecological consequences of single species dominance over mixed species may be taken into account.

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